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Estimation of the Herring Spawning Biomass near Isle Verte in the St.Lawrence Estuary From an Intensive Larval Survey in 1979

by

F. Auger (1) and H. Powles
Pêches et Océans Canada
Division des Sciences Halieutiques
Québec

Abstract

A spawning biomass survey of a small, spatially discrete herring population was performed by sampling yolk sac larvae near the spawning grounds with a small fast vessel. Total daily larval production was estimated from 5 cruises covering the spawning area; supplementary information from 4 stations in the area of peak yolk sac larval abundance, sampled at times other than the 5 survey cruises, was used to define the daily larval production curve. The weight-fecundity relationship was similar to that for Newfoundland herring and, with sex ratio, was used in estimating spawning biomass. Possible sources of error (temperature relationships for incubation period and time to yolk sac absorption, predation, temperature-related mortality) are discussed. An important source of error may have been inadequate spatial coverage linked to the daily and monthly tidal cycles in the estuary. Spawning biomass estimates ranged from 820 to 2700 mt depending on temperature chosen; most likely estimates were 1016 and 1960 mt. These estimates appear low in relation to annual catches from this population (⩾500mt).

Résumé

On a évalué la biomasse reproductrice d'une petite population de hareng bien définie dans l'espace en échantillonnant les larves à sac vitellin à l'aide d'une petite embarcation rapide. La production totale journalière de larves a été estimée à partir de 5 croisières d'échantillonnage qui ont couvert la région de frai au complet; des informations supplémentaires provenant de 4 stations dans la région d'abondance maximale de larves, visitées entre les 5 croisières, ont aidé à définir la courbe de production journalière de larves pour la période d'éclosion. La relation fécondité-poids, semblable à celle du hareng de Terre-Neuve, avec le sexe-ratio, ont servi à estimer la biomasse reproductrice. Les sources d'erreur possible (les relations de la période d'incubation et de la période d'absorption du sac vitellin avec la température, la prédation, la mortalité reliée à la température) sont discutées. Une source importante d'erreur est peut-être l'échantillonnage spatial imparfait des larves à sac vitellin à cause des courants reliés aux cycles de marée diurnes et mensuels. Les estimations de la biomasse varient entre 820 et 2700 tm selon la température utilisée; les meilleures estimations ont été de 1016 et de 1960 tm, que l'on considère comme basses en comparaison avec les captures annuelles provenant de cette population (⩾500 mt).

(1) Adresse actuelle: Département de Biologie, Université Laval, Québec

INTRODUCTION

The idea of estimating fish population size from egg or larvae surveys has been known since the turn of the century (Saville, 1963). Attempts to estimate spawning stock with this method have been made in Europe and America (Saville, 1963; Smith and Richardson, 1977). Standard techniques are reviewed by Smith and Richardson (1977). For Eastern Canada, Messieh (Pers. Comm.) used the technique to estimate the population of herring in the Northumberland Strait and Sinclair et al (1979) for Bay of Fundy herring. Maguire (1979) estimated mackerel stock size in the Gulf of St.Lawrence from an egg survey. The technique implies backcalculating the total number of eggs spawned by applying a mortality coefficient to the number of larvae (or eggs) sampled. Then, having an estimate of the proportion of mature females and an estimate of mean fecundity, the total abundance of the mature stock can be calculated. Many sources of error can affect results: estimates of fecundity, sex ratio, mortalities (on larvae and eggs), temporal and spatial coverage of the spawning areas and sampling methods.

The main source of error is temporal and spatial coverage of the larvae (or the eggs) (English, 1963). Based on his theoretical random model, confidence limits on the estimate of total number of eggs (or larvae) decrease with increasing number of cruises in one season. Thus, precise estimates require larger amounts of expensive ship time. So, to reduce costs and increase accuracy of the estimate of the total fish population, we tried to estimate daily larval production by sampling yolk sac larvae intensively near the spawning ground. A small fast boat was used to cover the region of high concentration of larvae in a few days, several times during the season. It was then possible to determine the shape of the daily production curve of larvae over time and by doing so calculate the total production of larvae. Bias due to inaccurate estimation of the mortality of larvae is reduced, since a main source of mortality (starvation and related events) occurs after yolk-sac absorption (May, 1973). Another source of error, underestimation of larvae because of net avoidance, is reduced or eliminated because of the use of only the smallest larvae in our method.

MATERIALS AND METHODS

In 1978 and 1979, during an extensive study of larval distributions, nine transects were visited along the south shore of the St.Lawrence estuary (6 in 1979) (Figure 1). At each transect, four ichthyoplancton tows, at 100m, 500m, 1 and 2 nautical miles from the shore were made; tows at 4 and 6 nautical miles were added in 1979. Stations were visited biweekly throughout the summer season. Figure 2 shows concentrations of herring larvae during the period of maximum seasonal abundance in 1978 and 1979. In both years, maximum abundance occurred at station 4, off Notre-Dame-du-Portage, a few miles upstream of Isle Verte where herring are known to spawn in the spring. Able (1978) found a large concentration of larvae south of Ile-aux-Lièvres in 1974 and 1975. Maximum seasonal abundances were recorded in the second half of June, 1978 and in the first half of July, 1979. Thus the area between Notre-Dame-du-Portage and Isle Verte was selected for a second sampling program involving intensive sampling for a spawning biomass estimate in 1979. In subsequent discussion, we refer to two sampling programs, the extensive (whole South Shore of the Estuary) and intensive (area of maximum herring larval abundance).

Estimation of daily production curve

During the intensive sampling program, daily larval production was estimated from cruises of 1 to 3 days (Table I), using a 21 foot Boston Whaler equipped with two 70/HP outboards. During each cruise, attempts were made to cover the entire patch of larvae. First, a transect of 5 to 6 tows was made, parallel to the coastline and at 2 nautical miles from the shore, from Isle Verte to a few miles west of Notre-Dame-du-Portage. This allowed us to locate the center of the patch. Then, several transects of 5 or more tows perpendicular to the coastline (continuing offshore until abundance of larvae was small) were done near the center of the patch. Tows were positioned by shoreline navigation.

At each station, a 10 min. oblique tow with a standard 0.5 diameter plankton net with mesh size .505 mm. at a speed of 2 knots was made. Standard 0.5m diameter plankton nets appear to sample 15-20mm herring larvae as effectively as bongo nets and 6ft square Tucker trawls in the St.Lawrence estuary (H. Powles and J. Dodson, unpublished data), so yolk sac larvae are probably effectively sampled by the 0.5m diameter net. Samples were preserved in 5% formaldehyde. Volume filtred was estimated with a General Oceanics flowmeter. Temperature and salinity were measured at surface (during the two last cruises bottom temperature was taken). Salinity was measured in laboratory with a Kahlsico induction salinometer.

In the laboratory, herring larvae were sorted and 50-100 were measured (standard length) depending of the range of the lengths. The presence of yolk sac was noted and its depth and length (lateral view) were measured to the nearest 0.1 mm. using a micrometer on a binocular.

For each tow, the number of larvae under 10 square meters was calculated according to the equation given by Smith and Richardson (1977).

Because tidal currents are strong in the Estuary, compensation for larval drift in these currents was necessary. Tow positions were moved from actual position to a position modified for tidal currents (direction and rate of the average tides from Canadian Hydrographic Services, 1979, map 1201). On the first day, all two positions were standardized to mid-day of the sampling day. For the following days, tows were moved to a later time corresponding to the difference in the high tide from the tide table (Canadian Hydrographic Services, 1979). For each tow, we defined a surface area by constructing a polygon by joining lines perpendicular to the mid point of the lines between stations. Surface area for each station was estimated using a planimeter. We then could calculate the total number of larvae for each length with the formula:

$$Ni = \sum_{J=1}^{S} F_{ij} \times C_j \times SR_j$$

where
- Ni = Total number of larvae of length i for one cruise
- Fij = Frequency of larvae of length i in tow j
- Cj = Total number of larvae under $10m^2$ for tow j
- SRj = Area in $10m^2$ for tow j
- S = Number of tows for one cruise

Incubation and yolk sac absorption time are temperature - dependent as shown by Blaxter (1956). We used his equations:

$$(T + 1.34) \times (Din + 2.00) = 165$$

and

$$(T + 0.77) \times (Drs + 2.50) = 231$$

where T = Temperature (°C), for estimating the incubation period in days (Din) and the period in days from spawning to complete yolk sac absorption (Drs). At low temperatures (0-4°C) the relationship for incubation time of Blaxter is quite different from that of Jean (1956), based on European and North American herring, but at temperatures observed during the present study the relationships are similar. A temperature/incubation period relationship of Hela and Laevastu (1970) gives somewhat longer incubation times than Blaxter's and has been used for comparison in later discussion. The maximum age of yolk sac larvae could then be estimated by Drs-Din and the average daily larval production for the period corresponding to that age with this formula:

$$P = \frac{\sum_{i=5}^{10} N_i}{D_{rs} - D_{in}}$$

and when constructing the daily curve applied it to the mid day cruise less (Drs-Din) ÷ 2. The yolk sac was present on larvae of 5.0 to 10.0 mm only (Figure 9), thus integration from 5 to 10 is performed in the equation.

To improve resolution of our estimate of the daily production curve, we used abundance of yolk sac larvae in four tows off Notre-Dame-du-Portage which were sampled on the extensive sampling program throughout the season in 1979 (Table 2). The four stations were sampled on both extensive and intensive programs. We assumed that the total number of yolk sac larvae present in these samples off Notre-Dame-du-Portage was directly proportional to the daily production, which was then estimated with this formula:

$$P_{jo} = \frac{P \times N_{jo}}{N_c}$$

where: Pjo = Daily production for the day jo

P = Daily production estimated during the nearest cruise of the intensive sampling program.

Nc = Total number of yolk sac larvae in the four tows off Notre-Dame-du-Portage (sum of the number under 10 m^2) during that cruise of the intensive program (Stations off Notre-Dame-du-Portage at high tide)

Njo = Total number of yolk sac larvae in the four tows off Notre-Dame-du-Portage (Sum of the number under 10 m^2) on day jo extensive sampling program (Tows all done at high tide).

Estimation of mean fecundity

Mean fecundity was estimated from 61 ovaries taken from a sample of 445 herrings bought from the commercial fishery in the area during May and June 1979. The ovaries, preserved in Gilson's fluid, were freeze dried, then weighed to the nearest 10^{-4} gram; the fecundity of each female was estimated using the weight of five subsamples of 200 eggs. Since fecundity of herring increases exponentially with weight of the fish (Messieh, 1976; Hodder, 1972), the population was divided into weight classes and fecundity of each weight class was estimated using the weight fecundity relationship calculated by linear regression. Mean fecundity of the population was taken as the weighted mean, using frequency of the weight classes.

Calculation of the spawning biomass

Blaxter (1956) showed that water temperature affects percent of hatching (Figure 3). For the spring herring of Clyde and North Minch, Scotland, as the temperature goes up the percentage of hatching goes down; the relation is inverse for fall herring.

The total number of eggs was calculated by:

$$NTot = \left(NTL \times \frac{100}{PC} \right) \div e^{-z(Din)}$$

and the spawning stock biomass by:

$$PB = \frac{NToT}{(Fec/gr \times 10^6) \times K}$$

Where
PB = Total Biomass in metric tons
NToT = Total number of eggs produced
NTL = Total number of larvae produced
PC = Percentage of hatching at temperature T. from the figure 3.
Z = Daily predation on the eggs on the spawning ground
Fec/gr = Mean fecundity per gram of body weight for the mature female
K = Proportion of mature female in the stock
Din = Incubation time in days at temperature T.

Predation on the eggs was estimated to be around 8% for 1 to 2 days by Caddy and Iles (1973) on the Georges Bank herring spawning ground. Tibbo et al (1973) estimated predation by the winter flounder (Pseudopleuronectes americanus) on the herring spawning ground of Pointe Blanchard, N.B., to be a minimum of 7% for the whole incubation period. Following Sinclair et al (1979), the maximum of 7% per day, applied during the incubation period estimated by the formula of Blaxter (1956) was used.

RESULTS AND DISCUSSION

Isometric lines, drawn by eye, showing larval concentrations under 10 m^2 were plotted for all larvae (Figure 4) and yolk sac larvae (Figure 5), for the intensive sampling program date. Larvae were concentrated between Ile-aux-Lièvres and Isle Verte. The distribution of yolk sac larvae was similar to the distribution of all larvae, except for the cruise of June 27-28. Production of young larvae apparently stopped between 19 and 31 July (Figures 5, 6). The total number of larvae for each length was calculated under the area delimited by the dotted lines (Figures 4, 5) because the yolk sac larvae distribution was not well defined by the tows. The zone was limited to south of Iles-aux-Lièvres because our results and those of Able (1978) indicated that herring larvae were concentrated in that region. Further GIROQ (Groupe Interuniversitaire de Recherche Océanographique du Québec) sampling in 1979 north of Iles-aux-Lièvres at the end of May, June and July showed small concentrations of total herring larvae (averages of oblique tows of Bongo separated by 3 hours over a 48 hour period at one station: May; 0/100m^3, June: 11/100m^3, July; .84/100m^3). (B. Jacquaz, Pers. Comm.).

The daily larval production was calculated for the five sampling cruises of the intensive sampling program, and the curve of daily production over time was constructed using the samples of Notre-Dame-du-Portage from both intensive and extensive programs (Table 3, Figure 7). It was then possible to calculate the total production of eggs by period between each cruise using the mean temperature of the cruise calculated from stations where there were yolk sac larvae (Table 4).

Weighted fecundity was calculated as 230 eggs/gr (Figure 8, table 5). The weight-fecundity relationship (Figure 8) is similar to those calculated by Hodder (1972) for Newfoundland herring. Using a proportion (K) of mature female in the stock of .54 (estimated from our sample of 445 herrings), we calculated a biomass of 1016 mt for the total stock.

A change in the temperature would modify percentage of hatching, length of incubation and yolk sac absorption period, and consequently the spawning stock estimate. If the calculations are done using the minimum and the maximum temperature on each cruise, our estimate varies between 820 mt and 2,700 mt. The latter estimate must be considered too high because at such high temperatures we have a very low hatching success (11% for the last two periods); bottom temperatures are probably lower on the spawning ground.

Hela and Laevastu (1970) give an exponential relation for the incubation period with temperature for herring eggs. Using their equation, the incubation period is longer (2 to 3 days) for the same temperature than Blaxter's (Table 4). Using the Drs calculated from Blaxter's equation but using Hela and Laevastu's for incubation period (Din), the total spawning stock estimate goes to 1960 mt.

Tremblay (1942) and de LaFontaine (1979) noted a downstream drift of herring larvae along the south shore of the estuary. This phenomenon might have a slight effect on our estimate; the drift of young larvae must be small since larvae appear to stay a long time in the area sampled as shown by the continual presence of post yolk-sac larvae during the last three cruises (Figure 6). The most important source of error in the estimate is probably tidal currents. The change in amplitude of the tide between neap-tide and spring-tide has an impact on the estuary ecosystem. The spring-tide produces mixing in the water column and the net downsteam transport per tide cycle increases markedly, up to 20 kilometers (Lafleur et al, 1979). This could cause a wider distribution (and greater dilution) of the daily larval production. The second and third cruises were done during spring tides and the two maxima in the daily production curve (Figure 7) correspond to neap-tide sampling; therefore, the total biomass may have been underestimated because a minimum average tidal current was used to reposition the tows.

The double-peaked shape of the larvae production curve (Figure 7) suggests the presence of two spawning runs in Isle Verte herring in 1979, with hatching from the two runs separated in time. Biological sampling and landings information from 1979 are insufficiently detailed to confirm this hypothesis. The peaks are separated by approximately 20 days. Because of the increasing water temperatures with time, separation of spawning peaks would be greater than this length of time; the spawning peaks may have been separated by one monthly tidal cycle.

Incorrect estimation of predation is a potentially important source of error. Sinclair et al (1979) noted that if they reduced the daily predation from 7% to 2%, their estimate of eggs produced was reduced by 50%. If we use the minimum value of 7% for the whole incubation period as estimated by Tibbo et al (1963), our estimate drops to 279 mt, smaller than the average landings over the last 13 years (Côté and Powles, 1978; 330 mt). In the Isle Verte region, in addition to predation by fishes, the common eider (Somateria mollisma) eats large quantities of herring eggs during the months of May and June (Cantin et al, 1974) so the maximum of 7% per day might be more realistic.

Percent hatching estimated from Figure 3 gave egg mortality larger than the values given in the literature (Hempel and Hempel, 1971: 4%, Baxter, 1971: 3.1 - 5.7%). This, therefore, might cause overestimation of the biomass.

Incomplete sampling of the yolk sac larval distribution is another potential source of error. If we compare the total number (Nb/100m^3) of yolk sac larvae in the samples along the entire south shore of the estuary (Figure I) in 1979, 82% of yolk sac larvae were caught at Notre-Dame-du-Portage and Isle Verte, the two stations within the area we used to estimate daily production. Most of the yolk sac larvae caught outside of this area, were caught downstream and could be the result of drift.

CONCLUSION

Table 6 shows the effect on the estimate of the principal sources of error discussed in the last section and others. Although maximum values from the literature of predation on the eggs and percent hatching were used, and thus we may have overestimated egg production, the biomass estimate appears small. Total biomass was roughly estimated by Côté and Powles (1978) from tag returns at 9,400 mt, probably an overestimate. It is possible that, due to the strong tidal currents of the region, we have not adequately sampled production of yolk sac larvae from this population.

Despite the possibility of incomplete larval sampling, we believe that this method could be useful with certain improvements. First, more accurate location of the spawning ground and sampling directly over it would be an improvement. Accurate sampling of new hatched larvae in an area affected by strong tides could be achieved by sampling hourly over a half tide cycle at a fixed station, measuring the current between each tow. Repeating this procedure several times at different locations would give a better estimate of the size of the patch since distances between each "tow" will be known with greater accuracy.

One difficult problem to resolve is the aging of the yolk sac larvae. It is impossible to use size of the yolk sac, since larvae hatch at different lengths and yolk sac sizes (Figure 9, Blaxter and Hempel, 1963). Better information could be obtained by measuring the duration of incubation and yolk sac absorption in relation to temperature with samples of eggs from the Estuary herring population.

Better estimates of egg mortality on the spawning ground of the estuary would also improve accuracy of later estimates.

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Table I: Information on the five cruises done during the intensive sampling program in summer 1979 for estimation of the spawning herring biomass.

Dates	Nb. of Stations	Mean Nb. of larvae under $10m^2$		Mean Surface (min-max)	
		Total	Yolk sac	Temperature	Salinity
May 24	3	0	0	6.3 (5.7-6.8)	-
June 12-14	12	94.4	90.4	7.7 (6.1-9.0)	22.3 (20.1-24.8)
June 27-28	14	294.9	6.2	9.8 (7.9-13.1)	22.3 (19.7-25.0)
July 17-19	29	2719.2	304.4	11.3 (7.3-16.7)	25.3 (23.3-28.8)
July 31-August 2	34	158.8	0	13.5 (9.6-18.5)	22.6 (18.5-26.3)

Table 2: Total number of yolk sac larvae in four tows off Notre-Dame-du-Portage during extensive survey program sampling in the 1979 season (Sum of the Number under $10m^2$ for the four tows)

Dates	Number of Yolk sac larvae	Dates	Number of Yolk sac larvae
May 16	0	July 23	0
May 28	1.5	August 16	0
June 22	1186.14	August 31	0
July 13	66.87	October 10	0

Table 3: Estimated daily production of yolk sac larvae in 1979 for the herring of Isle Verte, St.Lawrence Estuary.

Dates	Daily production
May 16	0
24	0
28	1.3×10^6
June 8	5.2×10^8
22	1.5×10^9
25	3.8×10^7
July 13	1.6×10^8
15	1.5×10^9
23	0
August 1	0
31	0
October 10	0

Table 4: Calculation of the total production of herring eggs near Isle Verte, St.Lawrence Estuary.

Periods	Total Number of Larvae produced (1)	Mean T°C	Percentage of hatching (2)	Din (3)	Total Number of eggs produced (4)
May 24-June 8	2.6×10^9	6.9	63	18	1.4×10^{10}
June 9 June 25	1.6×10^{10}	9.5	55	13	7.1×10^{10}
June 26-July 15	3.5×10^9	10.5 (5)	51	12	1.5×10^{10}
July 16-July 23	6.0×10^9	10.5 (5)	51	12	2.6×10^{10}
					TOTAL: 1.3×10^{11}

(1) Area under the curve of Figure 7.
(2) From Figure 3
(3) Incubation period in day from the equation of Blaxter (1956)
(4) Back calculation assuming a daily predation of 7% during incubation period.
(5) Bottom temperature from the cruise of July 17-19.

Table 5. Calculation of mean fecundity per gram for the herring of Cacouna and Isle Verte, St.Lawrence Estuary.

Weight classes (gr)	Frequency of occurence (%)	Fecundity (1)	Fecundity per gram
71-80	0.4	11,293	150
81-90	0.8	13,803	162
91-100	2.9	16,499	174
101-110	1.6	19,371	184
111-120	5.8	22,414	195
121-130	10.4	25,621	205
131-140	12.9	28,987	215
141-150	18.2	32,507	224
151-160	13.7	36,177	233
161-170	11.6	39,992	242
171-180	6.2	43,950	251
181-190	2.9	48,047	260
191-200	2.5	52,280	268
201-210	3.7	56,646	276
211-220	1.2	61,142	284
221-230	2.1	65,767	292
231-240	1.6	70,517	300
251-260	0.4	80,387	315
281-290	0.4	96,085	337
331-340	0.4	124,521	372
		Weighted mean:	230

(1) Estimated from Figure 8, using the middle of the weight class

Table 6. Effect on our estimate of the spawning biomass of herring of several potential sources of errors

Sources of errors	Effect on the estimate: underestimation	Effect on the estimate: overestimation
Percentage of hatching		X
Predation on the eggs		X
Predation on yolk sac larvae	X	
Tide currents	X	
Drift	X	
Mesh size	X	
Temperature relationships (Incubation period, time to yolk sac absorption)	X	X

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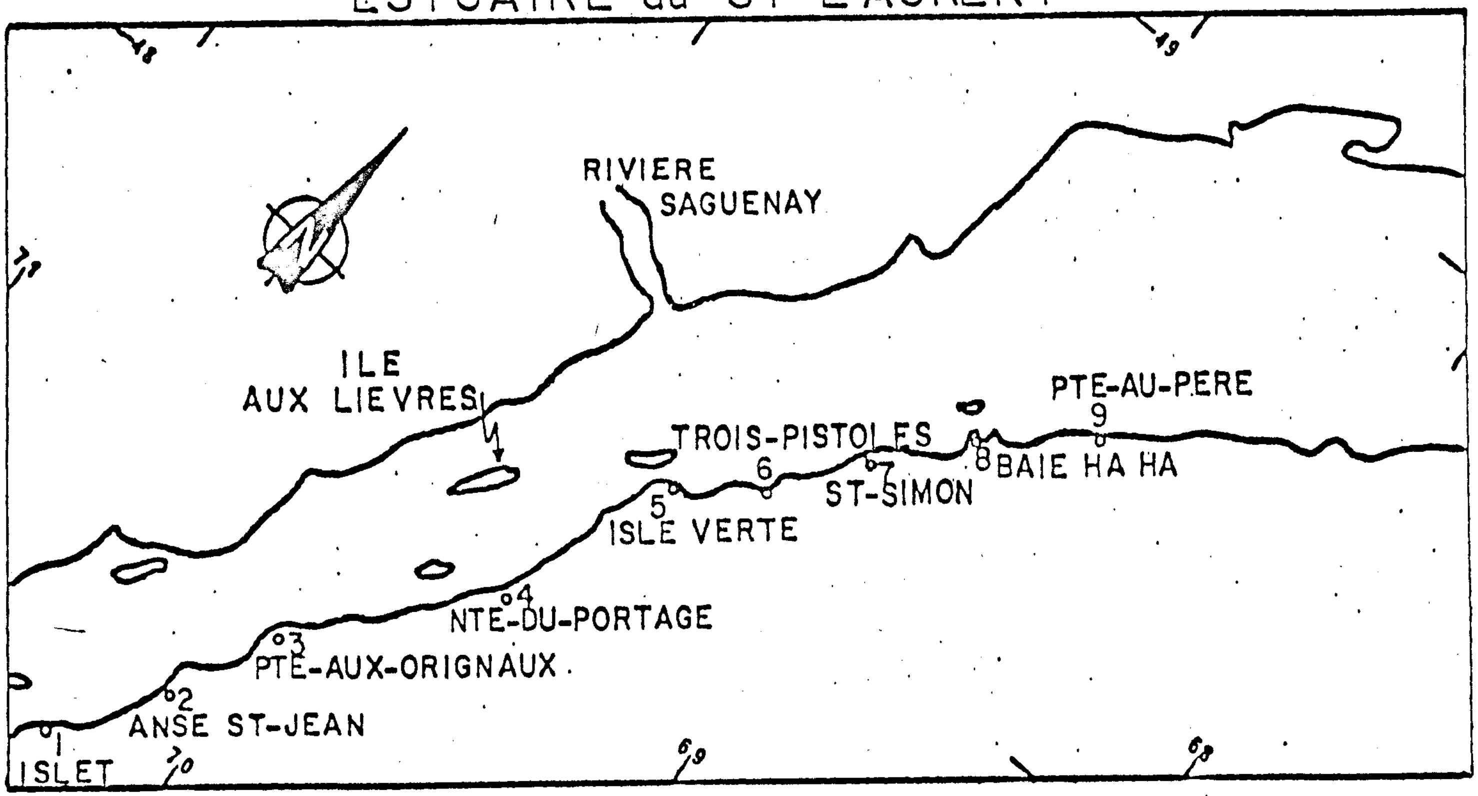

Figure 1: Position of ichthyoplanktons stations visited during the summers of 1978 and 1979. In 1979, only the stations 1, 3, 4, 5, 7 and 9 were visited.

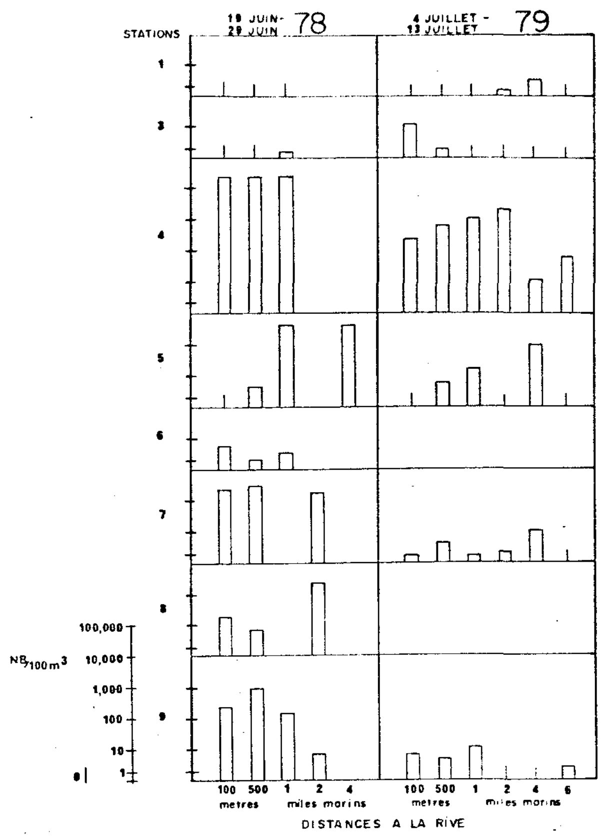

Figure 2: Concentrations of herring larvae (Number/100 m^3) along the south shore of the St. Lawrence Estuary at time of maximum abundance in 1978 and 1979. For the locations of the stations, see figure 1.

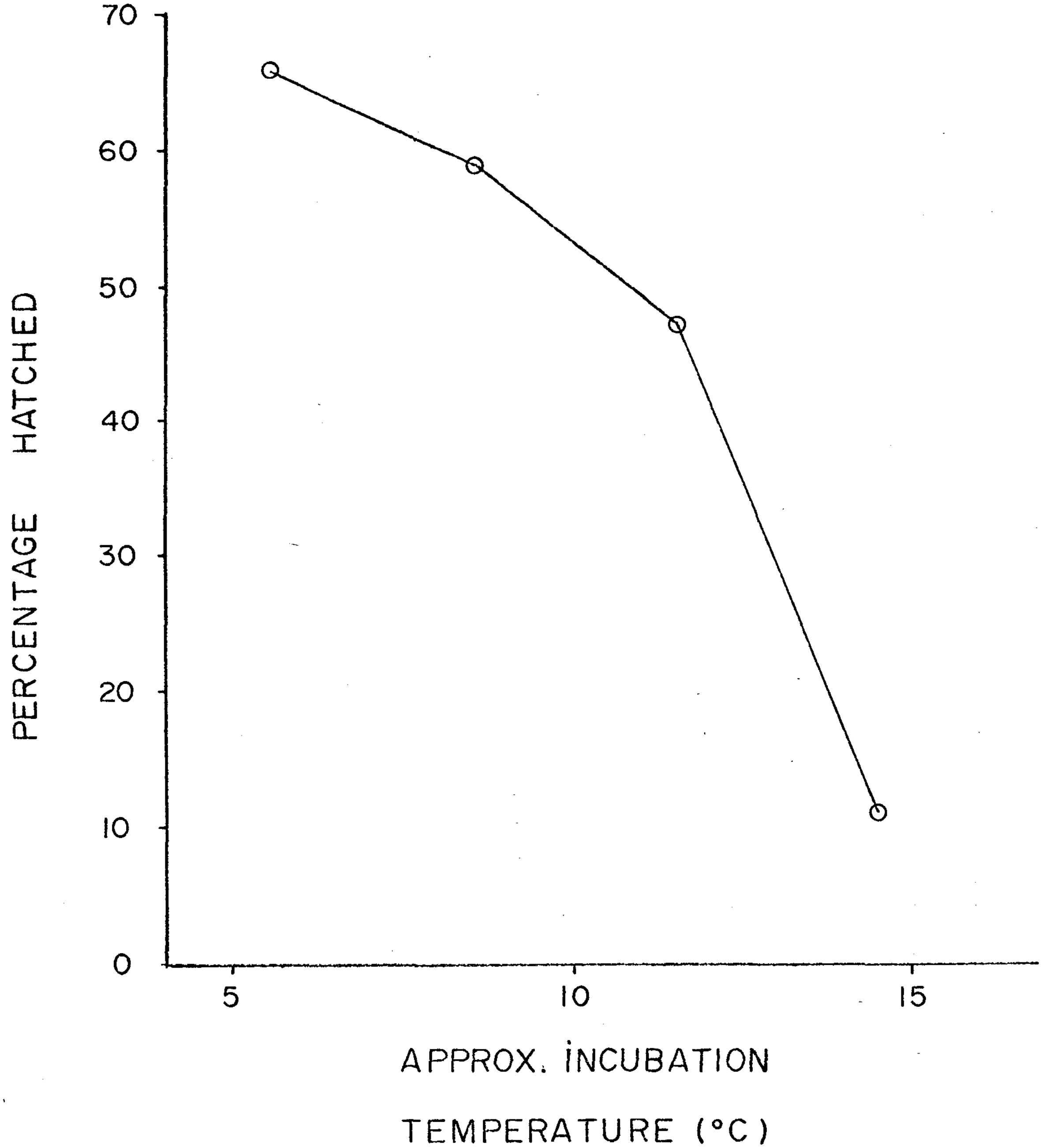

Figure 3: Relation between temperature of incubation and percent hatching of eggs for the spring herring of Clyde and North Minch, Scotland. Data from Blaxter (1956)

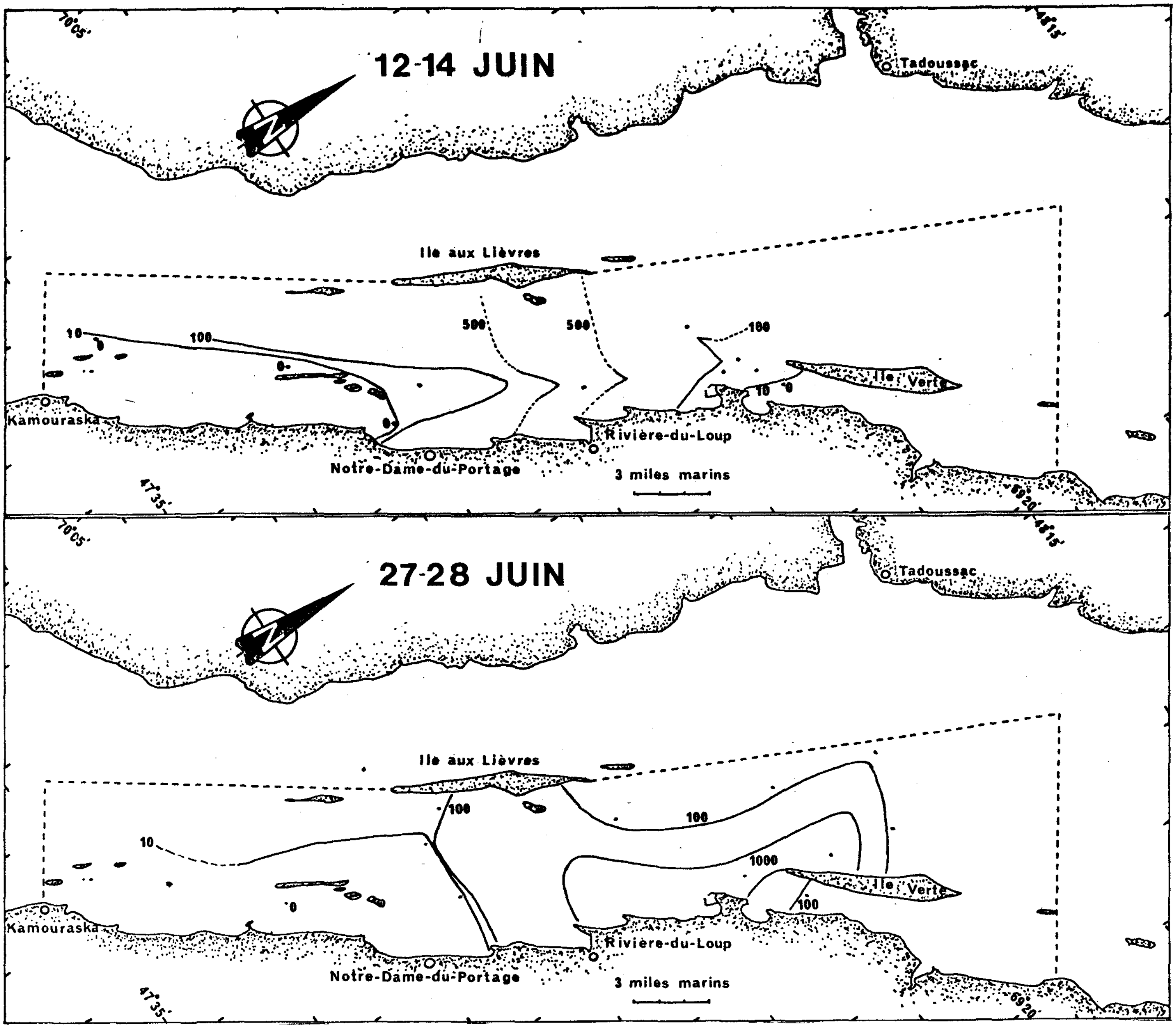

Figure 4: Isometric lines showing estimates of total larval abundance under 10 m^2 for each cruise in 1979.

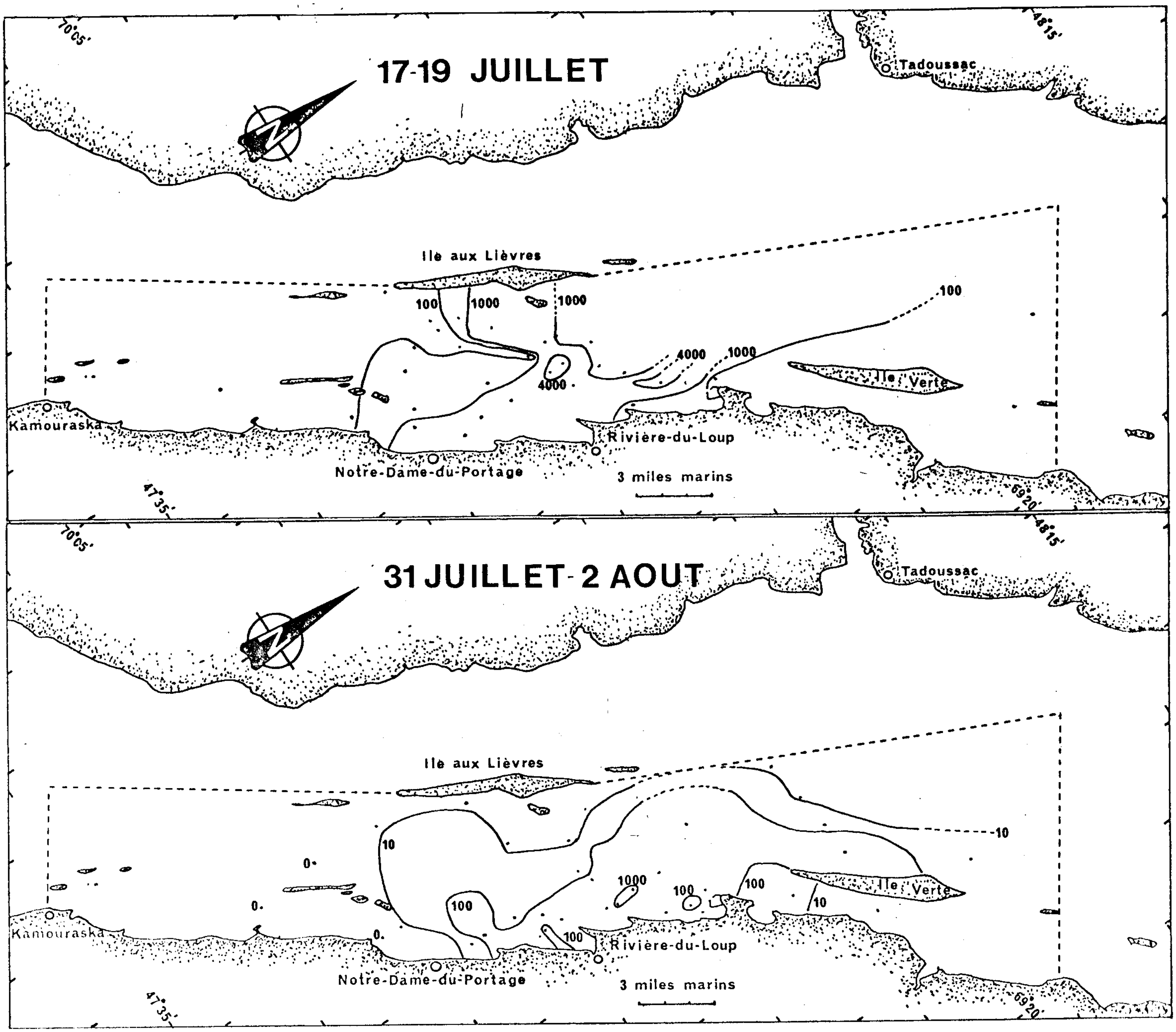

Figure 4: (concluded)

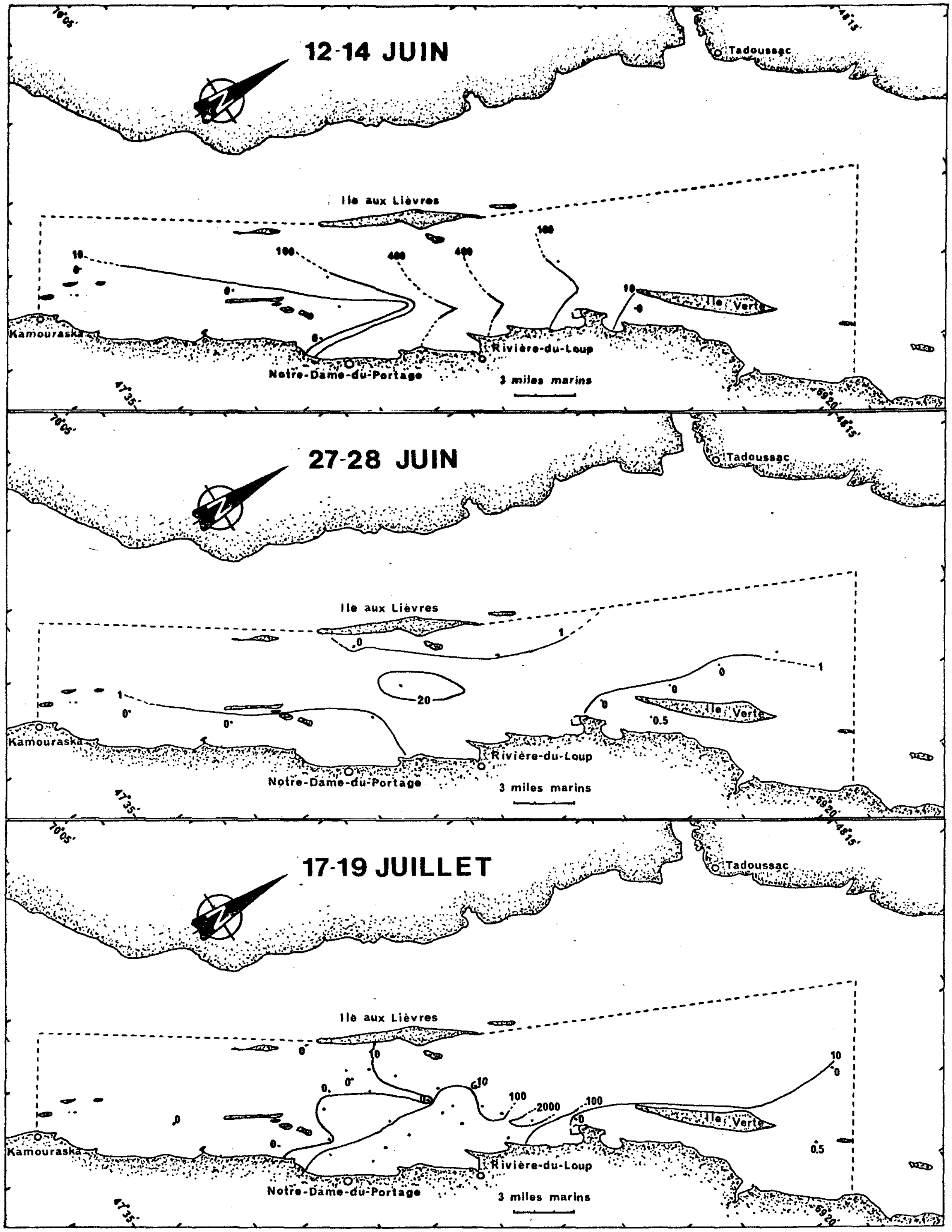

Figure 5: Isometric lines showing estimates of yolk sac larval abundance under 10 m^2 for each cruise in 1979.

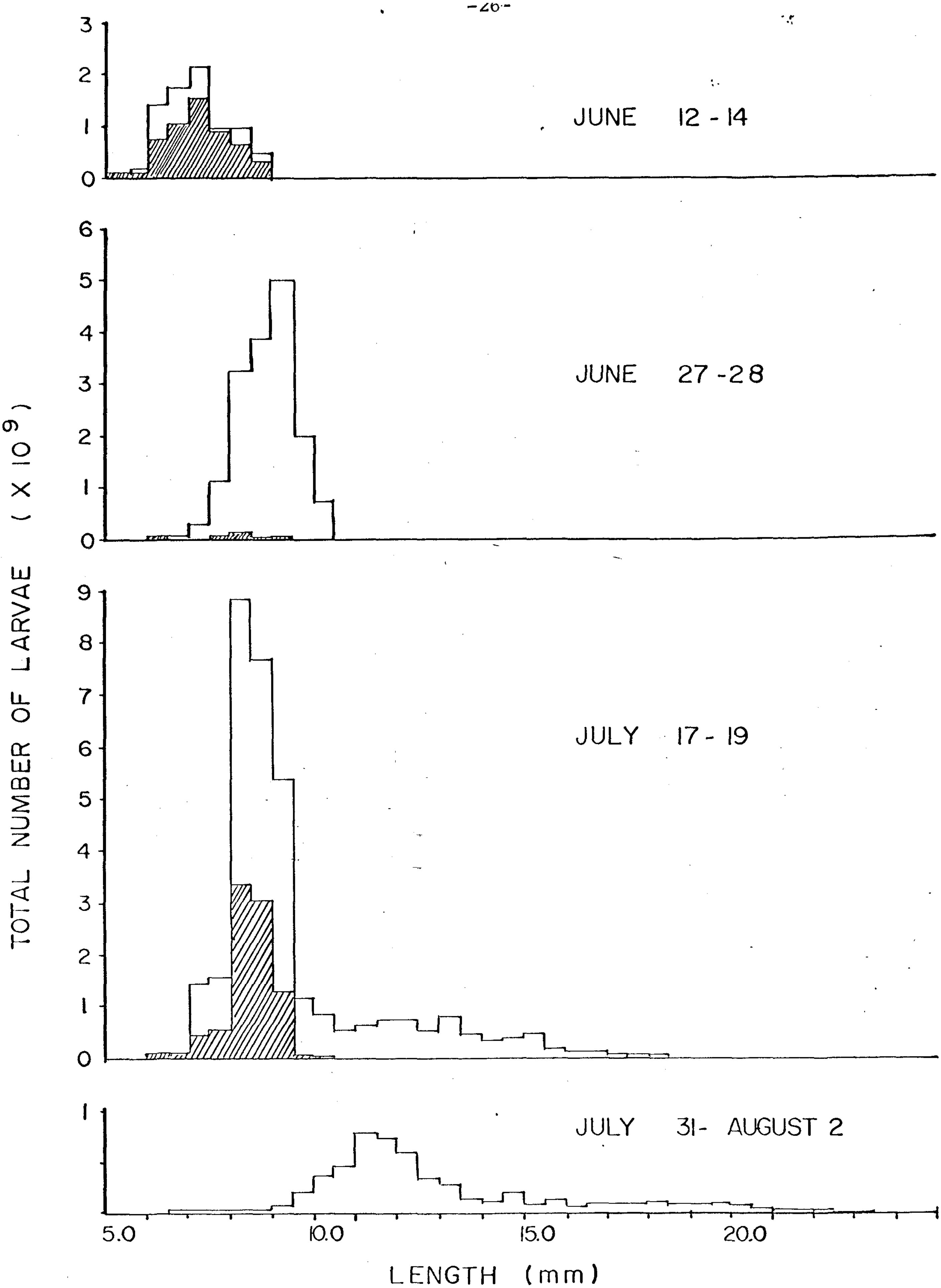

Figure 6: Length-Fequency of larvae for each cruise.
Shaded areas represent yolk sac larvae.

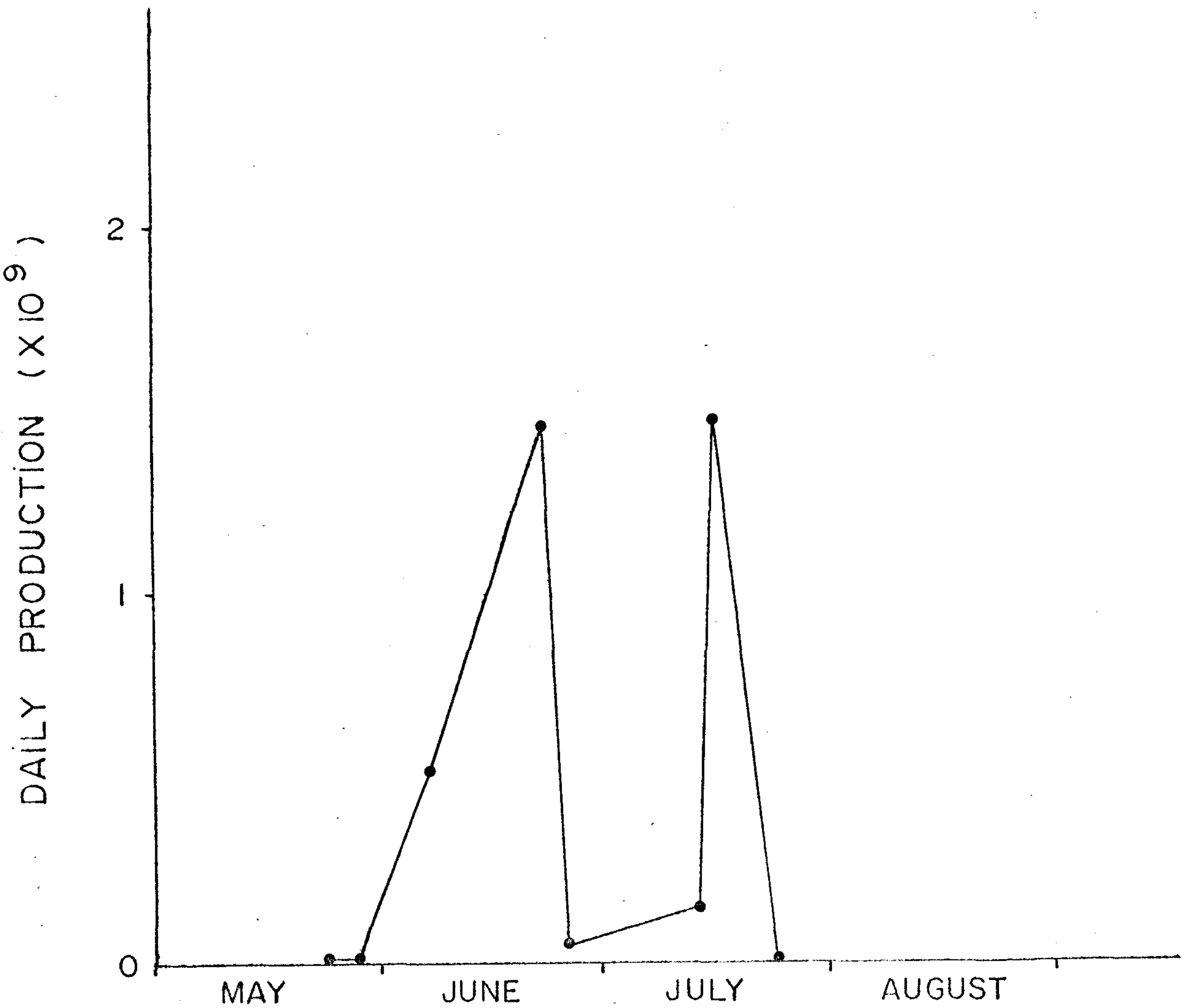

Figure 7: Estimated daily production of yolk sac larvae for the herring spawning ground of Ile Verte in 1979.

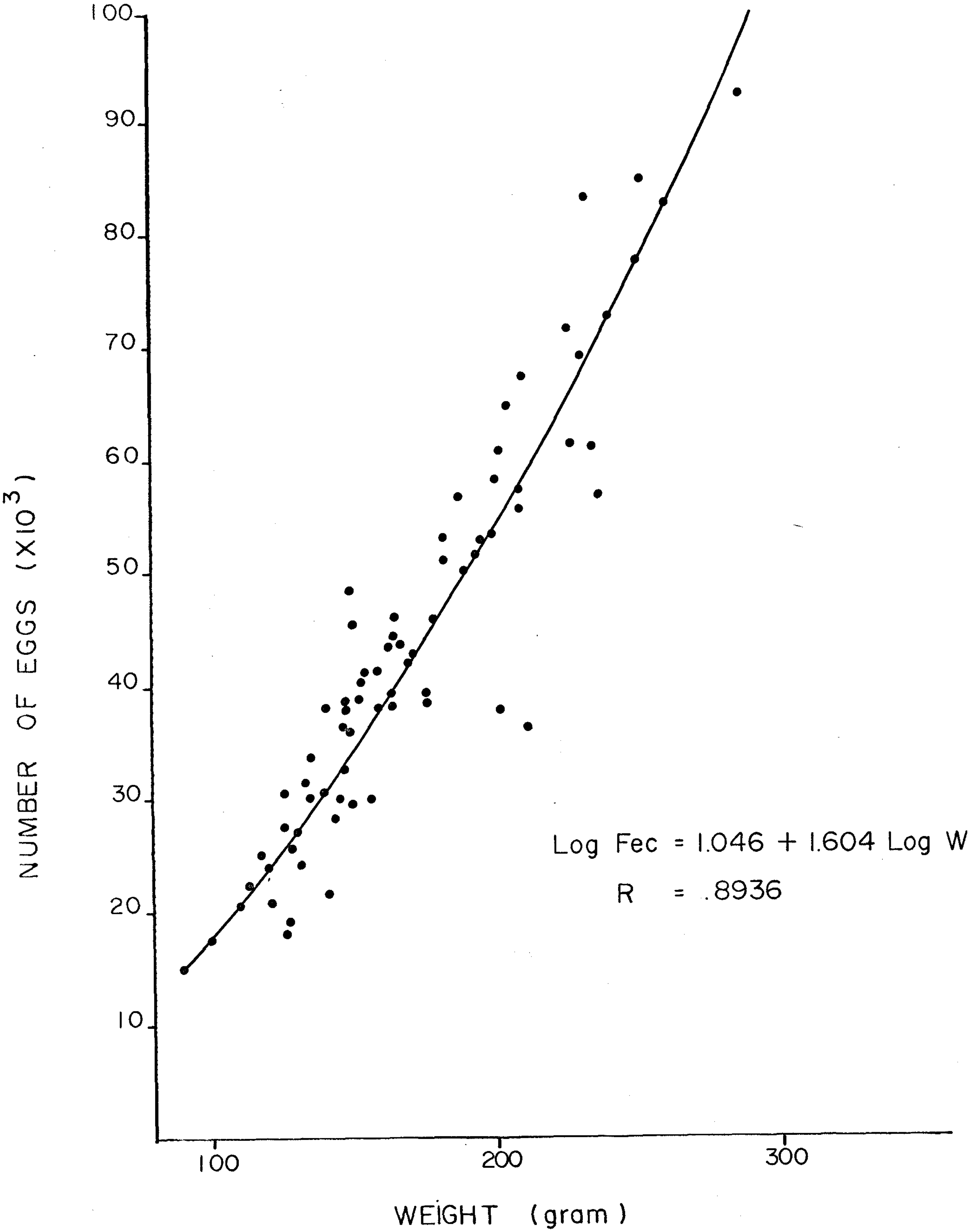

Figure 8: Fecundity-weight relationship for herring of Cacouna and Ile Verte, St. Lawrence Estuary.

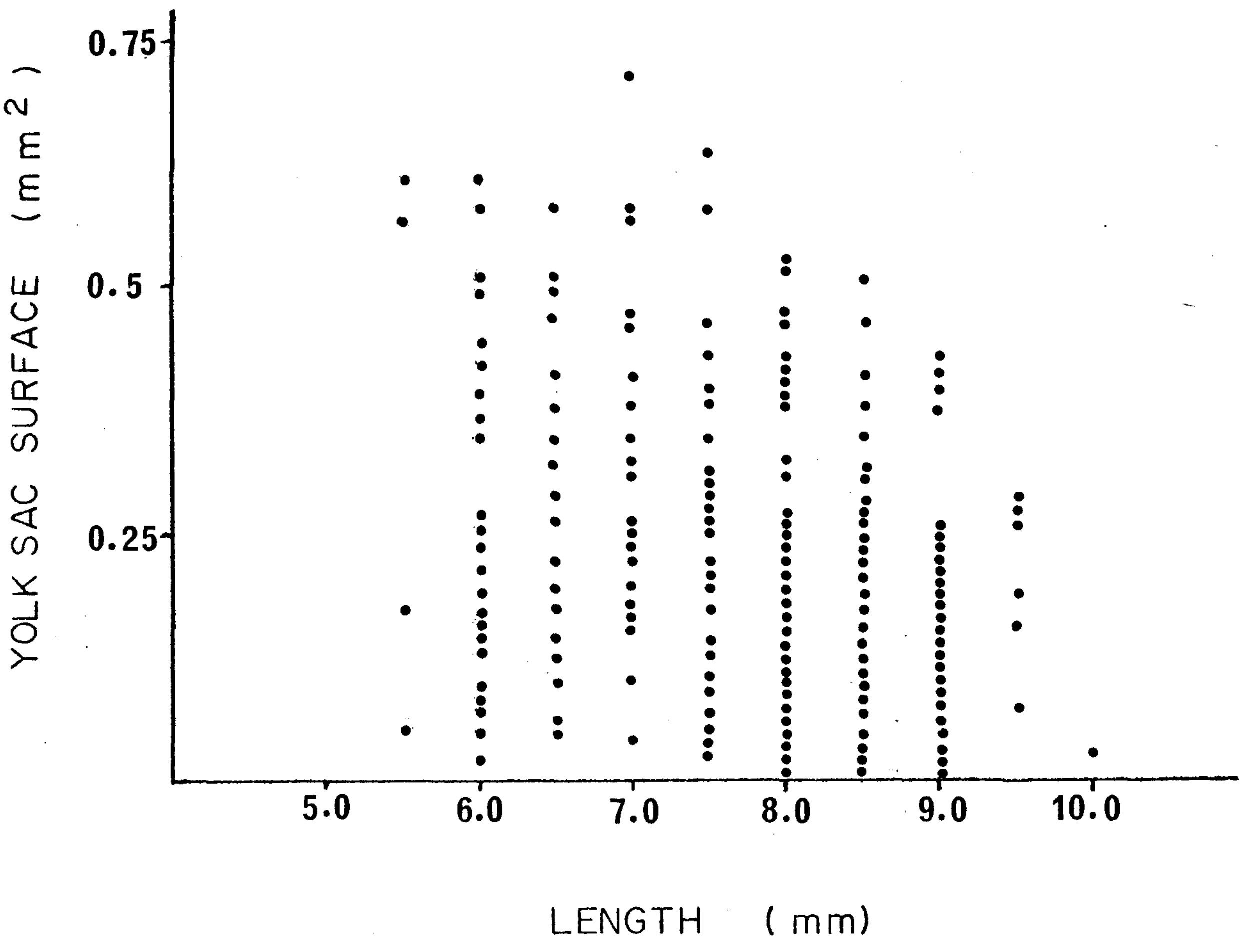

Figure 9: Yolk sac surface area (lateral, view, asuming elliptic shape) in relation to the length of larvae.